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RATING AN UNDERSHOT WEIR

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RATING AN UNDERSHOT WEIR

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PREFACE

The subject of this thesis is not new. It has been treated at various lengths by many writers and experimenters. However, the experiments heretofore made have been performed on orifices of small size and the results are not applicable to conditions as found in the irrigation canals of the Inter-Mountain country. It has been written with a view of producing a formula or a diagram by means of which the quantity of water, such as is ordinarily found in the canals of this country, may be measured as it passes under the regulating gates.

The author wishes to thank Dr. Richard R. Lyman, Professor of Civil Engineering, for his interest and aid in the experiments, the computations, and the final results of the work. This subject has been treated in two former theses, first by Messrs Scott P. Stewart and Howard V. Alston in 1908, and later by Mr. Arthur D. Taylor in conjunction with the writer in 1910. The results obtained for these theses have been incorporated in the present one, and thanks are due the above mentioned gentlemen for the use of their data.

The work has been pleasant and interesting, and if the results obtained can be put to practical use in the irrigation problems of the country, the author will feel amply repaid.

Salt Lake City,
May, 1911.

INTRODUCTION

With the building up and development of the West, and especially of the arid lands of this and neighboring states which are being brought under cultivation, comes the immense problem of irrigation. Lands formerly considered valueless for agricultural purposes are now being furnished with water and are proving of great productiveness and corresponding value. There are still large tracts of land above and not covered by the present canal systems which contain many acres which will, with water, be of as great value as an equal acreage of the land already under cultivation. Irrigation systems costing large sums of money have been built, and many more are being contemplated. The least expensive schemes have already been constructed and the possible remaining plans will no doubt be more costly and difficult of construction. However, as the land values increase, these plans will be worked out and the now arid lands irrigated. This naturally means that water for irrigation purposes is becoming more expensive, more valuable, and more difficult to obtain.

On account of the increasing value of water, companies and individuals concerned are becoming more exacting in their demands for their correct amount and proportion of water, and so therefore greater care is being exercised in measuring the quantities belonging to the various companies, canals, and individual users. Inaccurate methods of measurement have been the cause of a great deal of litigation and trouble in various parts of the country. In order to put an end to these troubles, it is necessary that a method shall be devised by which the water may be accurately and readily measured, and which at the same time, will not be expensive and will suit the conditions as they are found in the ordinary irrigation canals.

A number of different methods have been and are now being used in various places to measure the water and proportion it among the users. The overfall weir, when properly installed, gives accurate results, but is open to the objection of requiring special conditions for its operation and entails a considerable loss of head on account of the free fall required on the down stream side. It is necessary that the velocity of approach be as small as can conveniently be attained, and for this purpose, the channel of approach is usually made very deep, the crest of the weir standing at a considerable elevation above the floor of the channel. In a great many cases, the overfall weir cannot be used on account of the large amount of sediment which is carried by the water. This sediment, on account of the reduced velocity on the up-stream side, is deposited in the channel above the weir, and filling the channel increases the velocity of approach, rendering the weir inaccurate until the sediment is removed.

A current meter is used in many localities, but the instrument itself is very expensive and it requires an expert to use it to get accurate results. While an ordinary farmer may take the readings on a weir, unless the man using the current meter is thoroughly familiar with its use, and uses a great deal of care, the measurement is very apt to be far from correct. The current meter, then, is not suited for use in a large canal system on account of its first cost, and the expenses of the experts to use the instruments.

An orifice in a diaphragm is often employed, the orifice being of a stated size and under a definite head. The water falls free on the downstream side, that is, the orifice is not under water on the lower side. The "Miners Inch" is a familiar example of this method. The velocity of flow through an orifice of this character is dependent on the head on the orifice, the shape and size of the opening, the thickness of the diaphragm, and the condition of the edges, whether they are rounded, beveled, or square. The variation in these factors renders this method far from satisfactory or accurate.

For measuring water in irrigation canals, none of the above mentioned methods have proved satisfactory for all of the conditions. As a much better method of measuring and regulating the flow of water in the canals, and as a solution of the problem, the author suggests the use of the undershot weir, or as it is sometimes called, the inverted weir or submerged orifice. The apparatus, more fully described later in this paper, consists essentially of a diaphragm or gate which may be raised or lowered in the water, the water being forced to flow under the lower edge by the head due to the difference of water level on the two sides of the gate. The quantity of water flowing under the gate is dependent on the height of opening and the head.

The ordinary headgate in an irrigation canal, practically fills all the requirements of the weir, and since the headgates are already installed at all of the diverting points of the canal systems, they can readily be made to serve the purpose of weirs with a very small additional cost or trouble. A great advantage of this type of weir is that the loss of head is so small as to be almost negligible. This is a very important factor in many canals where the available fall is near the minimum and the loss for an overfall weir is a large item in the slope, and consequently in the velocity and the quantity of water flowing. With this type of weir, there should be no trouble with sediment, as the velocity of the water under the gate is high, and the water will sweep the channel clean, and will not allow the sediment to deposit and destroy the accuracy of the measurements. Since the mountain streams of this and neighboring states often carry large amounts of sediment, this method will in all probability prove the most accurate of all the methods so far devised for measuring these streams. The necessary measurements for computing the quantity of water are few, and after the weir is installed, any ordinary man may take the readings and record them.

The object of this paper is to arrange the results of the experiments performed in the Hydraulic Laboratory of the University of Utah, on weirs of this type, into a form which will be of use in measuring the flow of water under an ordinary headgate in a canal. The experiments were all made on two weirs, both of which were nearly the same length and design. The first was a temporary structure, while the second was made permanent. All the quantities have been reduced to cubic feet per second per foot of length of the weir, in order to make them applicable to any width. The weirs experimented on were about 6.25 feet and 6.4 feet long, being almost the full width of the channel in which they were placed, the latter being 2 meters or about 6.56 feet wide. The results obtained should apply to any length, however, and especially to the lengths of the headgates ordinarily found in irrigation ditches, as the lengths experimented on will not differ far from those usually employed.

Theory of the Undershot Weir.

A great variety of formulae which cover the conditions have been suggested by various experimenters and authors. The majority of these formulae are very complicated and involve a great many factors of a more or less indefinite value. The form of the equation is such that it is usually very slow of solution after the values of all the factors have been determined, making its use rather slow and tedious if the equation must be solved many times. In a number of cases, the formula given for the flow from a submerged orifice is the same as for free flow into the air, although usually the coefficient is different for the two cases.

Merriman suggests the formulae

$$V = \sqrt{2gh} \quad \text{and} \quad Q = AV = A\sqrt{2gh} = 8.02A\sqrt{h}$$

as giving the theoretical values of the velocity and quantity of flow from a submerged orifice, V being the velocity of flow through the orifice, Q the quantity of water, h the effective head on the orifice, A the area of the orifice, and g the acceleration due to the force of gravity or 32.2 feet per second per second. The effective head is the difference in elevation of the water on the two sides of the diaphragm. As a practical formula he gives

$$Q = CA\sqrt{2gh}$$

C being a factor depending on the shape, position, and condition of the orifice. He also gives a table of coefficients C, but as these factors cover very small openings, only, they are of no value in the present case.

The factors range from about 0.600 to 0.623.

Church in his "Mechanics of Engineering" gives the formula

$$Q = \mu F \sqrt{2gz}$$

which is the same as Merriman's, different symbols being used.

In writing on the flow of water through orifices, Daniel W. Mead in "Water Power Engineering" has the following: "It is found that water flowing through an orifice in the side of a vessel acquires a velocity practically equal to that which would be acquired by a falling body in passing through a space equal to the head above the center of the opening, i. e.

$$v = \sqrt{2gh} = 8.025\sqrt{h}$$

in which v = the velocity of the spouting jet

g = acceleration of gravity 32.2

h = head on the opening.

The discharge through the opening would therefore be

$$q = va = a\sqrt{gh}$$

or practically $q = ca\sqrt{2gh}$

where c is a coefficient varying with the size and shape of the orifice and with the various factors.

"A more accurate determination of the theory of flow through a given orifice is as follows:

"If a thin opening is considered at a depth y below the surface, the discharge through the elementary section 1 dy would be

$$dq = 1\, dy \sqrt{2gy}$$

Integrating this equation between the limits h_2 and h_1,

(h_1 and h_2 are the distances from the surface of the water to the upper and lower edges respectively, of the orifice) we obtain the following:

$$q = \tfrac{2}{3} l (h_2^{\frac{3}{2}} - h_1^{\frac{3}{2}}) \sqrt{2g}$$

or practically $q = m \tfrac{2}{3} l \sqrt{2g} (h_2^{\frac{3}{2}} - h_1^{\frac{3}{2}})$

m being the coefficient of practical modification due to the condition of the orifice".

In another place, in writing of submerged orifices Mead says: "But few experiments have been made on submerged orifices and tubes. These indicate a coefficient of about 0.62 for complete contraction which increases to 0.98 or even 0.99 with the contraction completely supressed".

Tudsberry and Brightmore, in "The Principles of Waterworks Engineering" have the following: "For a completely submerged orifice 2 feet long, 6 inches deep and 1/4 inch broad, with a difference of water level between the two sides from 1/4 foot to 3/4 foot, we found in a careful series of experiments, made in 1887, that the coefficient c in the formula

$$Q = cld\sqrt{2gh}$$

is 0.67; h being the difference in level of the water surface on the upper and lower sides of the orifice".

Fanning in his "Treatise on Hydraulic and Water Supply Engineering", under the head of "Equation of Volume of Efflux from a Submerged Orifice" says: "Neville suggests a formula for the discharge of water from rectangular orifices more theoretically exact than the above simple formula $(Q = CA\sqrt{2gh})$ as follows:

$$D = c\sqrt{2gh} \times \tfrac{2}{3} A \left[\frac{(h+\frac{1}{2}d)^{\frac{3}{2}} - (h-\frac{1}{2}d)^{\frac{3}{2}}}{d h^{\frac{3}{2}}} \right]$$

where D = volume of discharge.

A = area of orifice

h = head upon center of the orifice

d = depth of the orifice, or distance between its bottom and top.

c = coefficient of discharge.

"This formula can be advantageiously applied when the orifice is large and but slightly submerged, as is frequently the case with sluice gates controlling the flow of water from storage reservoirs or canals into flumes leading to water wheels, or with headgates of races or canals".

Fanning also makes a further reference to Neville, naming the "Third Edition of Hydraulic Tables", page 48. The book was published in London in 1875 and was not available to the writer of this paper.

"Hydraulics of Rivers, Weirs, and Sluices" by Molitor gives the formulae

$$Q = \mu_1 ab\sqrt{2gS}$$

$$S = \frac{v^2}{2g}\left[1 + \frac{B-b}{2b} + \frac{B}{2ab}(T_1 + H_2 - a)\right] + H_2 + \frac{nV^2}{2g}$$

where v = velocity of approach or the velocity of the water on the upstream side of the gate,

B = the total width of the channel

b = the width of the openings

V = the velocity of the water downstream side of the gate,

T_1 = the depth of the water on the down stream side of the gate,

H_2 = head on the orifice.

When V = 0, $S = H_2 + \frac{nv^2}{2g}$

For the case of top and side contraction and no bottom contraction $n = 0.67$.

For small sluices $\mu_1 = 0.4988 + \frac{0.271\sqrt{a}}{H - \frac{a}{2}} + 0.00093b$

For large regulating gates, $\mu_1 = 0.7069 + \frac{0.2717\sqrt{a}}{H - \frac{a}{2}} + 0.00093b$

Of the above formulae, the most common is

$$Q = CA\sqrt{2gh}$$

The formula is simple and easy to solve, and from the data obtained from the experiments, the value of C is easily determined. This value has been calculated for each of the runs and while there are a few wild points, the majority run very close together. There does not seem to be any definite regular change of C, paralleling a change of head, height of opening of the weir, or of the quantity, but the values vary without any regularity. For this reason, it seems that an average value, leaving out the wild points, will give a value of C which may be depended on as giving fairly accurate results.

The simplest formula covering the case which has come to the attention of the author is

$$Q = mh^n \quad \text{or} \quad \log Q = n \log h + \log m$$

When written in the latter form, the formula becomes the equation of a straight line, n being the slope and log n the intercept in the Y-axis, if log Q is the Y-coordinate, and log h the X-coordinate.

Messrs. Stewart and Alston employed this formula in their thesis, and for a height of opening of the weir of 0.197 feet, they adopted the following:

For heads between 0.14 and 0.40 feet, $Q = 3.7323\, h^{1.5578}$

For heads between 0.40 and 1.00 feet, $Q = 3.162\, h^{1.379}$

However, from the results obtained in the later experiments, the writer does not depend much on their values, as they do not check with the majority of the experiments.

The writer believes that a formula of this type fits the case and that the values of m and n are easily obtainable, and that the accuracy of the method will be sufficient for ordinary purposes. While the formula for each specific height of opening will not be written in this paper, a curve, to be described later, will be given, by means of which the value of m may be determined. The value of n was found to very closely approximate 0.5 so that the formula may be written

$$Q = m\sqrt{h} \quad \text{or} \quad \log Q = 0.5 \log h + \log m$$

By means of a series of curves to be later described, a diagram was drawn by means of which the quantity of discharge, for any head or height of opening of the weir within the limits of the drawing can be read directly.

Description of the Hydraulic Laboratory.

Location and Design.

Through the courtesy of Salt Lake City, the University of Utah has the privilege of running the water which supplies the Thirteenth East Street Distributing Reservoir through its laboratory. The Reservoir is on the corner of Thirteenth East and First South Streets, and the laboratory is situated on the hill immediately east of the reservoir. For the general arrangement and plan of the laboratory and reservoir, see Sheet # 7 . The land on which the laboratory is situated, is city property but the building, channels, weirs, etc., belong to the University. The capacity of the reservoir is about 6,000,000 gallons. The overfall weirs, channels, the measuring basin, etc. were designed by Dr. Richard R. Lyman and Professor W. E. Wilson of the Civil Engineering Department. The entire construction of channel walls, weirs, etc. is of reinforced concrete and steel. The valves are all of the gate type, operated by hand wheels.

Water Supply and Pipe Lines.

The water supply for the Thirteenth East Reservoir is conducted from Parley's and Cottonwood Canyons through a 42-inch by 42-inch brick and concrete conduit. This line is also the source of supply for the Fifth South line and is taped in several places to supply the South East Bench. What water remains after these demands are satisfied is discharged into a small receiving tank situated a short distance east of the reservoir. From this tank, it is conducted through an 18-inch vitrified pipe to an intake at the head of the University pipe line leading to the Hydraulic Laboratory. This intake consists of a concrete well 18 feet 4 inches by 15 feet 10 inches by 15 feet 4 inches. Originally the 18-inch vitrified pipe was continuous to the city reservoir, but at the time of the installation of the laboratory, the pipe was cut at the intake. The University laid an 18-inch machine banded wood stave pipe from the intake down to the head of the channels, the two pipes being parallel. At the intake, an elbow and four short lengths of pipe standing vertical make it necessary for the water in the intake well to rise above the end of this pipe in order to enter and flow down the vitrified pipe to the reservoir.

From the intake well, there are two lines of 18-inch pipe, one a vitrified line, the original, belonging to the City, and the other, the wood stave pipe, belonging to the University. The water ordinarily flows through the wood stave pipe, but can be made to flow through the other by closing a valve located just east of the discharge of the wood stave pipe. The intake well is about 70 feet higher in elevation than this valve, and so the static head on the lower end of the wood stave pipe is about 30 pounds per square inch.

Channels and Weirs.

After the water passes the valve in the wood stave pipe, it enters the upper channel of the laboratory. The channels or canals are all two meters wide with vertical walls. The upper canal is 50 feet long, and at the lower end is the first or Bazin Weir. The water then flows

wal second channel of the same dimensions as the first, discharging over the second or Cornell weir. Below the Cornell weir, the stream makes a right angle bend and flows west, passing the undershot weir, and then to the end of the channel which is about 50 feet long, where it discharges over the third or Utah weir. The discharge from here may be either into the measuring basin or into the diverting apparatus, which conducts the water directly into the reservoir. This spillway is about 25 feet east of the reservoir and about 15 feet above it.

Diverting Apparatus.

As shown on the drawing on Sheet # 8 , the diverting apparatus consists of a car about 7 feet by 8 feet in horizontal projection. It is built of two inch by 12 inch planks bolted to 6inch by 6 inch cross timbers, lined on the inside with sheet iron. The car is placed on a track so that it can be run back and forth as desired. When the car is run into a position tight against the lower end of the canals, the water flows over the car, falls about 15 feet and flows directly into the reservoir through a short concrete channel. When the car is moved forward, the water falls directly into the measuring basin.

At the upper end of the car, or the end nearest the weir, there is a vertical frame consisting of two channel irons, one on each side of the car. A wooden bulkhead is arranged to slide up and down between these channels. A rope, passing over a pulley fastened to the cross-piece at the top, is attached to the blukhead, by means of which it may be raised or lowered. When it is desired to push the car forward, the bulkhead is lowered, forming a tight obstruction to the water and the force of the water pushes the car forward. The bulkhead may then be raised ready for the car to be pushed back to its usual position.

Measuring Basin.

The measuring basin is simply a small concrete reservoir, 16 feet by 150 feet by about 10 feet deep. The construction is of concrete except the bulkhead at the north end, which is made of 12-inch by 12-inch timbers, well caulked with oakum. There is a 12-inch gate valve at the northwest corner of the basin by means of which it may be emptied. It may also be emptied by means of a rectangular opening about 2 feet by 3 feet, located immediately under the diverting car. This opening is covered with a cast iron plate which may be raised with a chain wound on an axle which is operated by a ratchet. When the basin is emptied by either method, the water flows directly into the reservoir.

The Undershot Weir.

The details of the undershot weir on which most of the experiments were made are shown on Sheet # 1 . The weir or gate consists essentially of a diaphragm which extends down into the channel and causes the water to flow underneath it, through the opening between its crest and the bottom of the channel. The gate is constructed of wood, the diaphragm being made of 2-inch planks, fastened to 2-inch by 6-inch uprights. These uprights are made to slide up and down in a couple of holes cut in a 4-inch by 6-inch timber which lies horizontally above the top of the wall. The gate slides up and down between 1-inch by 10-inch boards braced against the walls of the canal by means of a 2-inch by 2-inch scantlings running horizontally across the channel between them. The gate is made tight by means of oakum driven in the spaces between the planks, thin strips of wood being nailed on the downstream side to keep the oakum from being washed out by the pressure.

The weir is sharp crested, that is, its lower edge is sharp. As originally made, and as used for the experiments made by the author and Mr. A. D. Taylor in the spring of 1910, the lower plank of the gate was beveled to a point, the sharp edge being on the upstream side of the weir. It was found that this edge soon became broken and untrue. In order to provide a true edge which would not wear, a piece of plate steel 1/8 inch in thickness and 6 inches wide was, in the fall of 1910, fastened on the lower edge, the iron projecting about 1/2 inch below the beveled edge of the wood. This crest proved highly satisfactory.

As originally designed, and as used for the experiments made in the spring of 1910, there were a number of holes bored in the 2-inch by 6-inch uprights on the gates. These holes were staggered about 1 inch apart, and the gate was supported on pins passing through these holes and resting on the 4-inch by 6-inch timber across the top of the wall. There are three serious objections to this type of support. In the first place, when the head on the gate is very great, the pressure is so great that the gate is so great that the gate is moved with great difficulty, it being practically impossible for one man to raise it. A second objection is that as the wood composing the gate shrinks or swells, the distance from the holes for the pins to the crest of the weir is not constant, and so the exact height of the opening varies at different times for the same position of the pins. The third objection is that the pins become bent and untrue.

In order to eliminate these objections, some additions were made to the gate in the autumn of 1910. In the first place, a wheel and shaft was placed on the gate by means of which the gate could be raised or lowered. The shaft is forked at the lower end and is bolted to the gate. The wheel is held at the top of the cross piece of the gate support, the shaft raising and lowering through it. The other device added is one for determining the position of the gate, and thus the height of the opening between the crest and the floor of the channel. The device consists of two upright rods of iron 1/4 inch by 1-inch wide and about 6 feet long. These rods are placed about a foot from the ends of the gate. At the lower ends, they are riveted to the iron plate forming the crest. The rods are held in place against the gate by means of screws. These screws pass through slots in the rods about 1-1/2 inches long and about 3/8 inch wide, so that the swelling or shrinking of the wood does not affect the iron. Near the top of each rod is a niche made with a cold chisel. Fastened to the timber running across the channel above the wall are two short pieces of iron, so placed that the upright rods are in close contact with them. On each of these short pieces, there is also a niche. By measuring the distance between the niches in the upright and stationary piece on the cross timber, the position of the gate is determined.

The weir used by Scott P. Stewart and Howard V. Alston is described in their thesis as follows: "The weir is made of one-inch tongue and grooved Oregon Fir. The one-inch boards are nailed to cleats on each end which slide up and down against uprights secured to the concrete walls. Holes about one half inch apart serve to adjust the height of opening at the bottom of the weir. In order to prevent water from seeping around the edges of the diaphragm, strips of rubber belting are nailed to the face of the weir and allowed to project about an inch beyond the sides. As the water rises on the upstream face, these strips of rubber are squeezed tightly against the concrete walls and seepage is practically eliminated. As originally designed, it was intended to make a sharp-edged crest on the under edge of the weir; however, through faulty workmanship, this was not well done in this case. Much better results could be obtained in the opinion of the writers if a sharp forged shoe were fastened on as a crest instead of merely a board sharpened for the purpose".

The orifice below the weir is always completely submerged. The crest of the Utah weir, about 25 feet downstream from the undershot weir, is 1.65 feet above the floor of the channel, and the water flows over this crest to discharge from the channel. This makes the crest of the Undershot weir usually submerged about 1.5 feet. The amount of submersion is immaterial, but to carry out the theory of the weir, there must be some submersion.

Method of Measuring Undershot Weir.

Length of Weir.

The length of the inverted weir is the distance between the 1-inch by 10-inch boards on each side of the channel which act as guides for the gate in raising and lowering it. This distance was measured on the upstream side of the gate and as close to it as possible. Two plumb bobs were suspended near each side of the channel and close to the gate. The distance between the plumb bob strings was measured, the tape used being graduated to hundredths of feet, and the distance being estimated to thousandths. The distance from each plumb bob line to the boards mentioned above was measured with a scale, thousandths being again estimated. The sum of the three readings gave the length of the weir. The measurements were taken at the floor of the channel, and 0.25 feet and 0.5 feet above the floor. This covers the range of the heights of openings experimented on, and the average of these three lengths is taken as the length of the weir. The length of the weir experimented on by Messrs. Stewart and Alston was 6.23 feet. The width of the weir on which the remainder of the experiments were made was 6.44 feet, as determined by the author in conjunction with Mr. A. D. Taylor and as used in their calculations. The width of this weir, as measured in December 1910, was found to be 6.447 feet. This is the value used in all of the computations of the experiments performed by the author in the fall of 1910 and the spring of 1911. The construction of the guides of the gates was such as to cause a slight eddying effect, but this would not materially effect the results.

Height of Opening of the Weir.

In the case of the experiments performed by Messrs. Stewart and Alston, and by Mr. A. D. Taylor and the author, the gate was supported in certain definite positions by means of pins, resting on a stationary cross timber, placed in holes bored in the upright cleats. The height of opening for each position was obtained by direct measurement. The water was first drained from the channel in which the weir is placed, and then the gate placed in the various positions by inserting the pins in the various holes which were numbered. The distance between the crest of the weir and the floor of the channel was then determined with a scale. Readings were taken at intervals of one foot across the length of the weir. This method does not, in the opinion of the writer, give accurate results. The pins become bent, the holes in the uprights become worn, the pins dent themselves into the wood of the cross-piece, and the distance from the hole to the crest of the weir is not constant due to swelling and shrinking of the wood.

After the wheel and shaft for raising and lowering the gate were installed, the gate could be set at any point, there being no definite fixed points at which it was necessary to set it. The position of the crest with respect to the stationary iron block on the horizontal cross timber is determined at any time by measuring the distance, on each side of the gate, between the niche on the upright iron rod and the one on the stationary block. The mean of these two gives the position of the gate. In order to determine the height of opening for any position, the gate was set so that the average distance between the niches was 0.400 feet. After the water had drained from the channel, the distance from the crest to the floor of the channel was measured, with a scale, at intervals of 0.25 feet across the length of the weir. The distances were read to the closest 0.005 feet. The average distance between the floor of the channel and the crest of the weir for this position is 0.452 feet. Subtracting the 0.400 feet, which is the average distance between the niches, from 0.452 feet, the remainder or 0.052 feet is the height of opening of the weir when the niches coincide. This value, 0.052 feet, must be added to the average value of the distance between the niches to give the height of opening.

Measurement of the Measuring Basin.

The measuring basin has been carefully measured and the volume computed by several different parties of students. The width is measured by hanging two plumb bobs in the basin, one near each side, measuring the distance between the plumb lines with a steel tape, and the distance from each string to the wall at a foot interval from the bottom to the top, adding the readings thus obtained for the widths at the various sections. These widths are measured at 10 feet or 20 feet intervals along the length of the basin

The length is measured by the same method, usually however several plumb bobs being suspended in the length as otherwise the sag of the tape would be too great as the length is 150 feet. The length is measured in two or three sections.

From the lengths and widths so obtained, the averages for each foot are computed, and then the volume for each one foot lamina. From these values, it is necessary to subtract the volume of the seat for the large valve, under the diverting apparatus used for emptying the basin, and for the baffle plates near the south end. The difference of these quantities gives the volume of water the basin will contain in each foot of height of the water. The volume of the valve seat and of the baffles was carefully measured and calculated, and the values subtracted from the volumes computed from the average values of the length and width.

Method of Measuring the Head on the Weir.

The elevation of the water surfaces was determined by means of tapes with plumb bobs attached, The distances to the water surfaces from fixed points, some distance above the water was determined, on both the upstream and the down stream sides of the weir. Then, knowing the relation between the readings of the tapes when the water was at the same level on both sides of the gate, the head is easily determined.

The apparatus from which these measurements are made consist of bridges spanning the channel, on which there are fastened 2-inch by 4-inch uprights, to which are attached short blocks, also made of 2-inch by 4-inch pieces. These blocks are cut with a curved surface on the upper side at the front. The blocks have a hole cut near the back end up through which the tape passes. The tape lies on the top of the block, following the curve, and then falls to the water. On the underside of the block is placed a small iron plate, the bottom edge of which is used as the fixed point from which the readings are made. The tape, with the plumb bob fastened to it, is lowered until the point touches the water, and then the tape is read opposite the bottom of the iron plate mentioned above. The measuring block on the upstream side of the weir is 7 feet distant from the weir, the one on the down stream side being 19 feet from the gate.

Method of Determining the Relation Between the Tape Readings on the Upstream and Down stream Sides of the Weir.

The relation of the tape readings on the two sides of the weir may be determined by two methods, Care must be exercised to see that the same tapes and plumb bobs are always used in the same positions. The first method is by the use of a level and rod. The elevation of the two measuring blocks are first determined, and then the length of the two plumb bobs and their fastenings to the tapes. From these values the readings of the two tapes when the points of the two plumb bobs are in the same horizontal plane can be calculated.. The difference between these two readings is the relation sought.

The second method is by making the surface of the water on both sides of the weir at the same level, or in other words, shut off the flow, and let the water come to rest. Then suspend the two plumbs at their respective measuring blocks, and take a simultaneous set of readings, noting the time and the tape readings. If the height at which the water stands is varying, then the curve should be plotted between time as abscissae, and readings as ordinates, both sets being plotted on the same sheet to the same coordinates, and both being reduced by the same time, by correcting for the differences of the times shown by the two watches. Then draw lines through these points which will give a mean value of the readings. The average distance between these lines will give the desired relation of the tapes, the distance being read by the scale of the tape readings.

METHOD OF MAKING RUNS

Regulating the Quantity of Water.

By means of the 18-inch gate valve in the lower end of the 18-inch wood stave pipe described above, the water may be backed up in the pipe and in the intake well until it overflows into the vitrified pipe, and then into the reservoir direct. So long as this overflow is taking place, the head on the wood stave pipe remains constant, and so the quantity of water flowing in the pipe and through the channels of the laboratory is the same as long as the valve is not regulated. However, if the overflow stops, on account of a smaller quantity flowing into the intake,well than the valve is regulated to allow to pass into the channels, then the head on the wood stave pipe decreases and the quantity flowing also diminishes. Owing to the irregular demands of the Fifth South and other smaller lines tapping the conduit, the supply for the reservoir is also very irregular, and many runs were spoiled after being almost completed on account of a decrease in the quantity of water. A close regulation of the quantity of overflow is not advisable, but should always be a large stream. The quantity of water flowing in the canals and through the undershot weir is regulated by means of this large valve mentioned above, and by so doing the overflow in the vitrified pipe is also regulated.

Setting the Undershot Weir.

After the valve has been set, regulating the quantity of water for the experiment, the Undershot Weir is set in the desired position by means of the hand wheel. In order to set it at a certain definite position, the wheel is turned until the mean of the distances between the niches on the two sides of the gate correspond with the position desired. The average height of the opening under the weir is the sum of the mean distance between the niches on the iron rods of the gate, and the average distance from the crest of the weir to the floor of the channel when the niches correspond.

Elevation of the Water in the Measuring Basin.

Before the run is started it is necessary that there be at least enough water in the measuring basin to entirely cover the bottom, so that there is a level surface. Both valves, must, of course, be closed, so that no water will escape from the basin. After the surface of the water has come to rest, that is, the waves have ceased, the distance from the measuring blocks at each end of the basin to the water is measured. This is accomplished by lowering a tape, with a plumb bob at its end, over the measuring block. When the point of the plumb bob comes in contact with the surface of the water, the tape is read at a point opposite the bottom of the iron plate fastened to the bottom of the wooden block. Usually five readings are taken at each end of the basin, the average of each set being assumed to be the true distance.

Starting the Run.

After the conditions have become constant and the water surfaces in the channels have come to equilibrium, the run may be started. When all is ready, the diverting car is pushed forward, allowing the water to fall into the measuring basin. The time of turning the stream is noted. The diverting car may be pushed forward by two methods. If the quantity of water is large, the velocity of the water may be utilized to do the work by dropping the bulkhead across the upper end of the car, the force of the water pushing the car forward. In case this method is not used, the car must be pushed forward by means of a crowbar.

Measuring the Head on the Weir.

After the run is started, a number of readings are taken both above and below the weir to determine the distance from the measuring blocks down to the surface of the water. At times, the readings on the upstream side of the weir have been rather unsatisfactory on account of the waves occasioned by the fall of the water over the Cornell weir. The method of making these measurements is the same as that described above in determining the relative readings of the two tapes. In the majority of the runs, ten readings have been taken at each block, the average of the values obtained being used to determine the head. For the ordinary run, it was the practice to take five readings on each block at the beginning of the run, and five near the close. If there was any variation of the conditions, this method readily detected it, and it is believed that this system is much better than taking single readings every minute or two. Knowing the relative readings of the tapes with the water surface level, the head is easily computed.

Ending the Run.

The duration of the runs varied greatly for different amounts of water. The runs were not often stopped until the water surface in the basin had risen at least a foot. If a less amount of water had been used, a small error in the measurement of the elevation of the surface of the water would produce a large percentage of error in the computed quantity. For this reason, it was usual to make the runs shorter, the larger the stream of water being used. After sufficient water had passed into the basin, and all the measurements for head had been taken, the diverting car was pushed backward and the water again diverted into the reservoir, the time being again noted. As a usual practice, the car was pushed out and back on the even minutes, in order to avoid the use of fractions of a minute in the computations.

Measuring the Water in and Emptying the Basin.

After closing the run and regulating the quantity of water for the next run, the distance down the surface of the waterfrom the measuring blocks is again determined, five readings being taken at each end. If the basin is not full and has room for the water for a second or a third run, the following run may be started as soon as the conditions in the channels are settled, without making more readings on the basin. If, however, the basin is full, it may be emptied either by raising the big plate under the diverting car, or by means of the 12-inch valve at the north end of the basin. As the former is the more rapid, it is the method usually employed.

Notes for the Run.

The necessary notes for the run are but few and easily recorded. The number of therun and the date head the run. The position of the weir i s necessary, this being the average of the distances between the niches on the rod and plate on the two sides of the weir. Then the basin readings at the beginning of the run, specifying the north and south ends. Then the time of starting the run, must be given. The columns which the tape readings above and below the weir are recorded should be headed with the number of the tape and plumb bob used and where the readings are taken. The time of stopping the run and the basin readings at the end of the run complete the necessary notes.

Sample of Notes.

Run # 69.

April 24, 1911. Position of Undershot Weir 0.504'.

Time.	Basin Readings. S. End.	N. End.	Above Undershot Weir. Tape #4.	Below Undershot Weir. Tape #3.
11:24:00	11.132	11.077	2.835	3.465
	.133	.079	.851	.457
	.140	.080	.847	.453
	.160	.070	.835	.460
	.140	.056	.843	.462
			.878	.460
11:38:00	5.867	5.770	.859	.458
	.830	.765	.850	.457
	.818	.780	.850	.450
	.841	.801	.865	.470
	.869	.768		

Volume of the Measuring Basin.

The basin was very carefully measured on September 30, 1910 by Mr. J. W. Kramer and the author. The method used had been described above. The results of the measurement and the volume of each foot in elevation is shown in table #1. The volume of the baffle plates and of the large plate valve and its seat have been deducted. Since the values of the volumes for each foot do not vary far from the average, this value has been used in the computation, no account being taken of the position of the water surface. The average value of the volume per foot of height of the basin was computed to be 2400.234 cubic feet from this measurement.

The basin was measured by Messrs Stewart and Alston in 1908. In their computations they took into account the position of the water surface, and used the volumes of the particular sections in which the water rose. Their values, however, check closely with the ones used for the computations of the quantities for the experiments made during the year 1910 - 1911.

For the computations of Mr. Taylor and the author, an average value of the volumes obtained by the measurements made prior to 1910 was used as the volume. This value was used for all sections of the basin, no account being taken of the position of the water surface. The value used was 2398.851 cubic feet per foot of height of the basin.

Leakage of the Measuring Basin.

Several tests were made to determine the amount of water leaking from the measuring basin. The runs all extended over a period of at least ten hours, and some of them fourteen to seventeen. One run showed an increase of one tenth of a foot in depth in twelve hours. The other runs showed an average leakage of about 0.15 feet in 14 hours. As these values are so small as to reduce to a negligible quantity in cubic feet per second per foot of length of the weir, leakage was not taken into consideration in the computations of the experiments performed this year.

The measurements made by Messrs Stewart and Alston showed a considerable leakage and allowance was made for it. They made a number of leakage tests, and then plotted a curve between leakage in cubic feet per minute and height of the water surface above the floor of the basin. From their curve, they obtained the leakage for each run, and added the quantity to that shown by the measurement of the water in the basin, the total then being used to compute the quantity in cubic feet per second flowing under the weir.

The method used by Mr. Taylor and the author differed somewhat from that described above. The quantity of leakage was computed from several tests, in cubic feet per second, and a curve then plotted between the height of the water above the floor of the basin at the time of the tests and the leakage as determined above. Then the value of the leakage, read from the curve for any run, was added to the quantity in cubic feet per second computed from the measurements of the water in the measuring basin.

Computations.

Object and Methods.

The object of the calculations is to determine from the data taken at the time of the tests, the height of opening of the weir, the head, the quantity of water flowing in cubic feet per second per foot of length of the weir. Whenever possible logarithms have been employed in the computations, the six place tables found in Searle's Field Engineering being used. For computing the value of $C = \frac{Q}{A\sqrt{2gh}}$ and $A\sqrt{2gh}$, Thatcher's slide rule was used. All of the calualations have been carefully checked and while there are a number of wild points, this is, in all probability, not due to errors in the computations. A sample of the calculations will be given, and as the data for Run #69 has been given, the computations for this experiment will be shown below.

Height of Opening.

As shown by the notes, the position of the weir is 0.504 feet. This means that the average distance between the niches on the iron rod and plate on the gate is 0.504 feet. The average distance between the crest of the weir and the floor of the channel, when the two niches correspond is 0.052 feet. The height of the opening is the sum of these quantities, or 0.556 feet. Since the quantities are reduced to cubic feet per second per foot of length of the weir, the area of the orifice per foot is 0.556x1 = 0.556 square feet.

Head on the Weir.

Average reading of Tape# 3	3.460
" " " " # 4	2.851
Difference	0.609
	0.059
Head	0.550 feet.

0.059 feet is the difference of the tape readings when the watersurface is at the same level at both measuring blocks. This value was determined April 6, 1911, the data being recorded on page 48 of Book 9 of the Hydraulic Laboratory Field Books. The data is copied in Table #2. The average of the tape readings was computed and the difference determined, giving the relative reading of the two tapes.

Quantity of Water.

	S. End.	N. End.
Average Basin Readings before run	11.141	11.072
" " " after "	5.845	5.777
Difference	5.296	5.295

Average rise in the Basin 5.296 feet.

Log 2400.234	3.380253
" 5.296	<u>0.723948</u>
Total quantity 12,712 cu. ft.	4.104201
14 min.= 840 sec. Log 840	<u>2.923279</u>
Quantity in cu. ftl per sec. 15.133	1.179922
Width of weir 6.447 ft. Log 6.447	<u>0.809358</u>
Quantity in cu. ft. per sec. per ft. of length of weir 2.349	0.370564

The Constant C

Log 2g = Log 64.4	1.808886
Log h = Log 0.550	<u>9.740363</u>
Log 2gh	1.549249
1/2 Log 2gh	0.774624
2gh	5.951
Q/A (By Thatcher's Slide Rule)	4.221
Q (" " " ")	0.708

Explanation of Tables.

Table #1 gives the results of the measurement of the measuring basin in the Hydraulic Laboratory. The data was taken on September 30, 1910 by the author, assited by Mr. J. W. Kramer of the United States Mining Company. The computations were made by the author.

Table #2 is a copy of the data taken on April 6, 1911 to determine the relative readingsoof the tapes above and below the inverted weir, in order to be able to compute the head. The results show that Tape #3 reads 0.059 feet more than tape #4 when the water was at the same level under both measuring blocks. In order to obtain the head, subtract the reading of Tape #4, which is used above the weir, from the reading of Tape #3, used on the down stream side, and then subtract 0.059 feet from the result, giving the head in feet.

Table #3 and #4 give the results of all the runs, except a few valueless ones, made in the laboratory on the inverted weir. A note is made of the record of the original notes to be found in the field books of the Hydraulic Laboratory. The quantity in cubic feet per second per foot of length of the weirs is given in the last column of Table #4. The experiments numbered with "A" are the results of the tests of Scott P. Stewart and Howard V. Alston in 1908. The values of the quantity in cubic feet per second and cubic feet per second per foot of length of weir as given in their thesis, are incorrect, a value of the total quantity, uncorrected for leakage, being used. These values have been corrected by the author. A similar error was made in the computations of the results of the experiments made by Arthur D. Taylor and the writer in 1910. These values have also been corrected, and the experiments are lettered "B". The experiments marked "C" have been made by the author and members of the class in Experimental Hydraulics in 1910 - 1911.

Table #5 gives the results of the computations made to determine the value of C in the formula $Q = CA\sqrt{2gh}$

Table #6 gives the heights of opening, head, and quantity, with the logarithms of the two latter. The fifth column is the value of 0.5 log h, and is called log Qc. The last column gives a value found by subtracting log Qc from the logarithm of the quantity as measured.

Table #7 is a series of values read from the curves on Sheet #2. The explanation of the values is given under the discussion of Sheet #3.

Table #8 gives the values of the intercepts, on the lines log h = 0.0 and log h = -1.0, of the lines representing the heights of openings, as drawn on Sheet #4. It also gives the limits of the curves, that is, the logarithm of the heads in the range of the experiments.

Table #9 gives a list of intercepts similar to Table #8, the values being read from the curves on Sheet #5, and being used to draw the height of opening or area of orifice lines on Sheet #6.

Explanation of Drawings.

Sheet #1 gives the details of the Inverted Weir as at present constructed. The gate and its fastenings were designed by Mr. Arthur D. Taylor. The original tracing has been lost, so a copy was made, using a blue print of the original as a guide, by the writer and the later improvements added.

On Sheet #2 are plotted the results of all the experiments made on the inverted weir, the coordinates being the logarithms of the head and quantity. The values are taken from Table #6. A series of lines were drawn between the points of equal height of opening representing as nearly as possible an average of these values. It was found that these lines are all practically parallel, the slope being 0.5. The equations of these lines, then, may be written

$$\text{Log } Qc = 0.5 \text{ log} h + \text{log } m$$

where log m is the intercept on the Y-axis. Table #7 is a list of the values of Log m for the various heights of opening. Since the mean value of log m is about 0, the trial formula, used in Table #6, log Q = 0.5 log h, was used.

Sheet #3 shows a curve plotted between the values of heights of opening and log m as read from Sheet #2 and recorded in Table #7. From this curve the value of log m for any height of opening in the limits of the drawing may be read and the quantity of water flowing then determined, being given by the formula log Q = 0.5 log h + log m.

Sheet #4 gives a number of series of points plotted between log h and the values of (log Qm-Log Qc), Log Qc being equal to 0.5 logh. The values plotted were taken from Table #6. A series of stright lines were then drawn representing as closely as possible a mean of the individual points for the various heights of openings. It was desired to transfer these curves to another sheet, where the coordinates were log h and log Q. In order to do this the values of the intercepts of these curves on the lines log h 0.0 and log h -1.0 were read, these values being given in Table #8. The following explanation will render the method clear.

The trial formula used in determining the values of (log Qm - log Qc) is log Qc = 0.5 log h.

When $h = 1.0$ $\log Qc = 0$

" $h = 0.1$ $\log Qc = -0.5$

" $h = 1.0$ $\log Qm - \log Qc = \log Qm.$

" $h = 0.1$ $\log Qm - \log Qc = \log Qm + 0.5$

and since $\text{Log}\ Qc = 0.5 \log h + \log m$

when $h = 1.0$ $\log Q = \log m$

when $h = 0.1$ $\log Q = \log m + 0.5.$

For this reason, the intercepts read from Sheet #4 for $\log h = 0$ is correct but for $\log h = -1.0$, 0.50 must be subtracted from the value read from the coordinate ($\log Qm - \log Qc$). The results in Table #8 are corrected for this value.

Sheet #5 shows two curves, plotted from the data in Table #8, the coordinates being height of opening and the values of the intercepts determined above. From this curve, the values given in Table #9 were read.

Sheet #6 was plotted by first laying out the coordinates log h and log Q. The intercepts on the lines $\log h = 0.0$ and $\log h = -1.0$ as given in Table #9 were then plotted and the lines representing the heights of opening or area of the orifice were then drawn between the two intercepts. Laterthe true values corresponding to log h and log Q were located and the lines representing them drawn.

The remainder of the sheets give the plans and details of construction of the Hydraulic Laboratory.

Suggestions for the Installation of the Weir.

For a good installation of the Undershot Weir, the bottom edge of the gate should be protected by a steel plate so as to prevent wear, and to keep the crest true and sharp. A method must be provided to determine accurately the distance between the crest of the weir and the floor of the channel. An apparatus similar to the one installed on the Experimental Weir and described above is recommended. The other apparatus necessary would be two plumb bobs and tapes, one to be used above the weir and the other on the down stream side. A suitable place must be provided to suspend and read them. The plumb bob used on the down stream side of the weir should be at some distance below the gate, say 15 feet, on account of the fact that near the gate, the velocity is so great as to make the elevation of the water surface less than it is further down stream. It is important that the crest of the weir be always submerged, otherwise the results obtained here will not apply.

In the installation in the laboratory, the gate occupies practically the entire width of the channel. In order to use this method of measurement at a diverting point in a canal system, it would be best to build a flume for a short distance and put the gate, a few feet, say at least 6 feet back from the main canal in the diverting channel. Then the conditions would practically duplicate those of the laboratory, as regards to velocity and direction of approach.

Methods of Determining the Quantity of Water Flowing

First.

One method by which the quantity of water flowing in cubic feet per second per foot of length of the weir can be calculated is by the formula $Q = CA\sqrt{2gh}$. A is equal to the area of the orifice in square feet, but since the weir is assumed to be one foot wide, A is numerically equal to the height of the opening in feet. The average value of C as obtained from the computations of these experiments is 0.664. The values vary from about 0.62 to 0.71, and the opinion of the writer is that the above value may be assumed to be practically correct. Tudesbury and Brightmore (See reference under Theory of Undershot Weir, page 8) give C the value of 0.67 from a similar set of experiments.

Second.

A second method would be by the formula $Q = mh^n$ or $\log Q = n\log h + \log m$. From the curves on Sheet #2, it is seen that 0.5 may be assigned as the value of n, giving the equations the form

$$Q = m\sqrt{h} \quad \text{or} \quad \log Q = 0.5 \log h + \log m.$$

The values of log m for various heights of openings may be read from the curve on Sheet #3 and substituted in the formula.

Third.

Another method, involving no computations whatever, is by means of the diagram on Sheet #6. With a known head of water, and a known height of opening, the quantity may be read direct from the table by locating the intersection of the head and area of orifice lines, then interpolating if necessary for the quantity.

CONCLUSION.

The result of the experiments show very clearly that water may be accurately measured by means of the Inverted Weir. The results of the experiments with the exception of a few wild points, show a very small variation from the mean of the entire set. All seem to follow closely a set of general laws, which have been deduced and the formulae worked out.

These experiments do not, by any means, exhaust the field. More experiments might well be made with higher heads than have been possible in the present case. Then, various lengths should be experimented with to see if the length of the weir does not enter as a factor in the quantity of discharge. In order to make the application still more general, a set of experiments might be profitably made on a weir set in the side of a canal with the water in the main canal flowing past and at right angles to that flowing under the weir and into the diverting channel.

It is the opinion of the writer, that, under similar conditions to that prevailing in the position in which the experimental weir is placed, the Inverted Weir is one of the most accurate methods of measuring water so far in use, besides being economical to install and use, and offering no additional obstructions to the stream. The Inverted Weir should soon have a wide application and use all over this Western Country.

Table #1.

Volume of the Measuring Basin.

Section	Average Width.	Average Length.	Volume	Volume of Baffles and Valve.	Net Vol.
1st ft.	16.041	150.002	2406.190	11.672	2394.518
2d ft.	16.035	150.005	2405.760	8.158	2397.602
3d ft.	16.034	149.998	2405.195	7.985	2397.210
4th ft.	16.036	150.005	2405.270	3.700	2401.570
5th ft.	16.038	149.980	2405.430	4.072	2401.358
6th ft.	16.032	149.985	2404.969	2.757	2402.212
7th ft.	16.037	149.977	2404.874	4.021	2400.853
8th ft.	16.043	149.975	2405.619	3.105	2402.269
9th ft.	16.063	149.985	2407.529	3.260	2404.269
			Average		2400.234 cu.ft.

Table # 2.

Comparison of Tapes.

Time.	Tape #4 Above Weir.	Time.	Tape # 3 Below Weir.
3:04:56	4.368	3:05:00	4.420
05:15	4.365	:35	4.402
:30	4.365	06:10	4.432
:42	4.368	:30	4.421
:55	4.365	:50	4.424
06:05	4.365	07:05	4.422
:17	4.366	:30	4.421
:30	4.367	:45	4.421
:52	4.365	:55	4.420
07:25	4.363	08:00	4.430
:45	4.362	:15	4.420
08:10	4.365	:30	4.421
:25	4.365	:45	4.424
:35	4.364	09:00	4.421
:52	4.362	:10	4.430
09:12	4.362	:30	4.430
:25	4.365	:45	4.432
:42	4.368	:55	4.430
10:25	4.365	10:10	4.425
:50	4.366	:25	4.426
11:00	4.367	:35	4.421
:09	4.365	:45	4.426
:19	4.365	:55	4.424
:31	4.363	11:05	4.425
		:15	4.426

Comparison of Times

Hannibal	3:13:11	Tape #3
Becraft	3:13:00	Tape #4

Average Readings.

Tape #3	4.424
Tape #4	4.365
Difference	0.059

Table #3.

No. of Run.	Field Record. Book.	Page.	Date.	Length of Run in Min.	Rise in Basin.
A 2	6	23-24	4/29/08	9	1.206
3	6	23-24	4/29/08	12	1.599
4	6	19-20	4/28/08	22	1.360
5	6	27-28	5/7/08	9-7/60	1.488
6	6	23-24	4/29/08	13	1.755
7	6	23-24	4/29/08	9	1.205
8	6	27-28	5/7/08	8	1.289
9	6	27-28	5/7/08	11	1.802
10	6	17½-18	4/28/08	13	2.317
11	6	25-26	5/7/08	7	1.146
12	6	23-24	4/29/08	16	2.187
13	6	16-17	4/27/08	30	5.170
14	6	19-20	4/28/08	18	1.308
15	6	21-22	4/29/08	12	1.612
16	6	16-17	4/27/08	30	5.157
17	6	21-22	4/29/08	17	2.771
18	6	17½-18	4/28/08	16	3.803
19	6	21-22	4/29/08	14	1.877
20	6	25-26	5/7/08	5	0.972
21	6	25-26	5/7/08	12	2.182
22	6	17½-18	4/28/08	7	1.375
23	6	25-26	5/7/08	5	1.129

Table #3 (Cont)

No. of Run.	Field Record. Book.	Page.	Date.	Length of Run in Min.	Rise in Basin.
B 2	5	52	3/31/10	17	2.525
3	5	52	3/31/10	15	2.014
4	5	52	3/31/10	15	1.520
5	5	52	3/31/10	16	3.475
6	5	53	3/31/10	15	2.420
7	5	53	3/31/10	15	2.124
8	5	57	4/13/10	15	0.997
9	5	57	4/13/10	17	1.136
10	5	58	4/27/10	30	4.890
11	5	59	4/27/10	20	4.926
12	5	60-61	5/6/10	30	2.773
13	5	61	5/6/10	30	2.243
14	5	64	5/11/10	20	4.643
15	5	64	5/11/10	25	5.785
16	5	65	5/11/10	21	4.018
17	5	68	5/16/10	20	3.880
18	5	68	5/16/10	30	5.729

Table #3 (Cont.)

No. of Run.	Field Book.	Record. Page.	Date.	Length of Run in Min.	Rise in Basin.
C 1	9	10	11/14/10	120.15	0.810
2	9	10	11/14/10	90.10	1.398
3	9	12	11/14/10	75.19	1.795
4	9	14	11/15/10	60.06	2.011
5	9	14	11/15/10	80.5	3.457
6	9	16	11/15/10	50.7	2.810
7	9	16	11/15/10	30.4	2.104
8	9	17	11/15/10	25	2.097
9	9	18	11/16/10	190	0.917
10	9	23	11/21/10	40	5.735
11	9	23	11/21/10	50	6.644
12	9	24	11/21/10	35	4.089
13	9	24	11/21/10	35	3.857
14	9	25	11/21/10	35	3.106
15				30	Discard.
16	9	27	12/6/10	70	4.115
17	9	31	3/16/11	20	4.862
18	9	31	3/16/11	21	4.620
19	9	32	3/18/11	50	4.229
20	9	33	3/18/11	60	3.649
21	9	33	3/18/11	40	4.741
22	9		3/29/11	20	Discard.
23	9	37		11	4.284
24	9	38		18	6.532
25	9	39		16	5.938
26	9	41	3/30/11	44	6.350
27	9	42		30	4.019
28	9	42		31	4.070

Table # 3 (Cont.)

No. of Run.	Field Book	Record. Page.	Date.	Length of Run in Min.	Ri se in Basin.
29	9	43		70	4.025
30	9	45	4/1/11	25	5.893
31	9	45		30	6.432
32	9	46		25	5.974
33	9	46		35	7.080
34	9	50	4/15/11	20	5.542
35	9	50		17	2.310
36	9	51		30	3.049
37	9	51		30	2.472
38	9	52		30	1.937
39	9	52		30	1.459
40	9	53		30	0.609
41	9	54		30	0.336
42	9	55	4/17/11	20	3.834
43	9	55		20	3/512
44	9	56		20	2.764
45	9	56	4/17/11	30	3.046
46	9	57	4/17/11	30	3.593
47	9	57	4/17/11	30	2.522
48	9	58	4/17/11	60	0.627
49	9	58	4/17/11	50	1.086
50	A 5	75	4/19	30	1.367
51	A 5	75	4/19	30	0.943
52	A 5	76	4/19	30	0.761
53			4/21	30	5.282
54			4/21	30	4.821
55			4/21	30	4.410
56			4/21	30	3.463
57			4/21	30	2.642

Table # 3, (Cont.)

No. of Run.	Field Book.	Record. Page.	Date.	Length of Run in Min.	Rise in Basin.
C 58			4/21	26	1.773
59	9	60	4/22	10	1.736
60	9	61	4/22	20	1.845
61	9	61	4/22	30	1.754
62	9	62	4/22	60	1.717
63	9	62	4/22	70	2.990
64	9	63	4/22	30	3.342
65	9	63	4/22	20	2.624
66	9	64	4/22	30	2.875
67	9	65	4/24	60	3.230
68	9	65	4/24	45	1.874
69	9	66	4/24	14	5.296
70	9	66	4/24	7	2.223
71	9	67	4/24	11½	4.095
72	9	67	4/24	9.30	3.658
73	9	68	4/24	8	3.330
74	9	68	4/24	16	3.290
75	9	69	4/24	16	3.076
76	9	69	4/24	20	1.049
77	9	70	4/24	45	1.050
78	9	70	4/24	45	1.050
79	4	21	4/25	30	3.641
80	4	21	4/25	30	3.198
81	4	22	4/25	30	2.739
82	6	85	4/26	30	3.506
83	6	85	4/26	30	2.922
84	6	86	4/26	30	2.134
85	6	86	4/26	30	1.525

Table #3 (Cont.)

No. of Run.	Field Record. Book.	Page.	Date.	Length of Run in Min.	Rise in Basin.
C 86	6	87	4/26	30	1.123
87	6	88	4/26	25	2.523
88	10	1	4/28/11	25	5.529
89	10	1	4/28/11	25	4.900
90	10	2	4/28/11	30	5.250
91	10	2	4/28/11	30	4.245
92	10	3	4/28/11	25	2.928
93	9	71	5/13/11	30	1.573
94	9	71	5/13/11	30	1.217
95	9	72	5/13/11	20	2.650
96	9	72	5/13/11	10	1.673
97	9	73	5/13/11	15	4.022
98	9	73	5/13/11	9	2.745
99	9	74	5/13/11	15	2.801
100	9	74	5/13/11	15	3.251
101	9	75	5/13/11	15	2.766

Table # 4.

No. of Run.	Height of Opening.	Head.	Q^1, cu. ft./	Q^{11} Cu.ft./sec.	Q, Cu.ft/sec. per ft. length.
A 2	0.490	0.141	2916	5.400	0.867
3	0.460	0.180	3860	5.361	0.861
4	0.197	0.183	3760	2.848	0.457
5	0.490	0.206	3588	6.560	1.053
6	0.291	0.229	4223	5.414	0.869
7	0.314	0.233	2907	5.385	0.864
8	0.460	0.276	3104	6.467	1.038
9	0.376	0.285	4335	6.568	1.054
10	0.376	0.316	5580	7.154	1.148
11	0.314	0.470	2753	6.555	1.052
12	0.220	0.475	5248	5.476	0.878
13	0.291	0.481	12292	6.830	1.096
14	0.106	0.619	3148	2.915	0.468
15	0.197	0.697	3878	5.386	0.685
16	0.197	0.941	12413	6.896	1.107
17	0.197	0.967	6646	6.516	1.046
18	0.291	1.068	9135	9.514	1.527
19	0.140	1.078	4519	5.380	0.864
20	0.220	1.101	2340	7.800	1.252
21	0.197	1.170	5251	7.602	1.220
22	0.197	1.261	3285	7.822	1.256
23	0.291	1.362	2706	9.020	1.448

Table #4 (Cont.)

No. of Run.	Height of Opening.	Head.	Q^1 cu. ft.	Q^{11} Cu. ft. per sec.	Q, Cu. Ft. per sec/ft. length.
B 2	0.216	0.596	6057	6.051	0.940
3	0.216	0.465	4831	5.436	0.844
4	0.216	0.292	3694	4.216	0.655
5	0.386	0.392	8336	8.740	1.357
6	0.386	0.214	5805	6.573	1.021
7	0.386	0.171	5094	5.732	0.890
8	0.091	0.656	2392	2.660	0.413
9	0.091	0.716	2725	2.709	0.421
10	0.303	0.363	11730	6.604	1.025
11	0.303	0.861	11817	9.927	1.541
112	0.131	0.565	6652	3.125	0.485
13	0.131	0.401	5381	3.086	0.479
14	0.479	0.302	11138	9.336	1.450
15	0.648	0.153	13877	9.354	1.452
16	0.820	0.079	9639	7.712	1.197
17	0.563	0.138	9308	7.814	1.213
18	0.479	0.232	13943	7.734	1.201

Table #4 (Cont.)

No. of Run.	Height of Opening.	Head.	Q^1 cu.ft.	Q^{11} Cu.ft. per sec.	Q, Cu.Ft./sec. per ft. of length.
C 1	0.088	0.011	1944	0.263	0.041
2	0.088	0.044	3356	0.620	0.096
3	0.088	0.108	4308	0.953	0.148
4	0.087	0.197	4827	1.339	2.208
5	0.087	0.333	8297	1.727	0.268
6	0.087	0.522	6745	2.243	0.348
7	0.087	0.850	5050	2.799	0.434
8	0.116	0.824	5033	3.356	0.520
9	0.052	0.004	2201	0.193	0.030
10	0.212	0.595	13765	5.736	0.890
11	0.212	0.604	15947	5.316	0.825
12	0.212	0.385	9815	4.674	0.725
13	0.212	0.384	9258	4.408	0.684
14	0.212	0.226	7455	3.550	0.563
15	Discard.				
16	0.102	0.412	9877	2.352	0.365
17	0.291	0.961	11670	9.725	1.508
18	0.291	0.756	11089	8.801	1.365
19	0.156	0.386	10151	3.384	0.525
20	0.156	0.200	8758	2.433	0.377
21	0.156	0.762	11 380	4.741	0.735
22	Discard.				
23	0.556	0.563	10283	15.580	2.417
24	0.556	0.503	15678	14.517	2.252
25	0.556	0.514	14253	14.846	2.302
26	0.197	0.700	15241	5.733	0.895
27	0.197	0.587	9647	5.359	0.831
28	0.197	0.515	9769	5.252	0.815

Table #4 (Cont.)

No. of Run.	Height of Opening.	Head.	Q^1 cu.ft.	Q^{11} Cu. Ft. per sec.	Q. Cu.Ft./sec per ft. length
C 29	0.197	0.126	9661	2.300	0.357
30	0.306	0.762	14145	9.430	1.463
31	0.306	0.635	15438	8.577	1.330
32	0.306	0.801	14339	9.559	1.483
33	0.306	0.566	16994	8.092	1.225
34	0.556	0.228	13302	11.085	1.719
35	0.556	0.070	5544	5.436	0.843
36	0.306	0.161	7318	4.066	0.631
37	0.220	0.198	5933	3.296	0.551
38	0.220	0.125	4649	2.583	0.401
39	0.091	0.402	3502	1.946	0.302
40	0.091	0.076	1462	0.812	0.126
41	0.052	0.058	807	0.448	0.069
42	0.291	0.581	9203	7.669	1.189
43	0.291	0.479	8430	7.025	1.090
44	0.291	0.300	6634	5.529	0.858
45	0.291	0.168	7311	4.062	0.630
46	0.291	0.239	8624	4.791	0.743
47	0.291	0.118	6053	3.363	0.522
48	0.052	0.055	1505	0.418	0.065
49	0.052	0.223	2607	0.869	0.135
50	0.091	0.332	3281	1.823	0.283
51	0.091	0.179	2263	1.257	0.195
52	0.091	0.128	1827	1.015	0.157
53	0.291	0.551	12678	7.043	1.093
54	0.291	0.396	11572	6.429	0.997
55	0.291	0.386	10585	5.881	0.912
56	0.291	0.233	8312	4.618	0.716

No. of Run.	Height of Opening.	Head.	Q^1 Cu. ft.	Q^{11} Cu. Ft. Per Sec.	Q cu. ft. per sec/ft. length.
C 57	0.291	0.128	6341	3.523	0.546
58	0.291	0.080	4256	2.728	0.423
59	0.220	0.890	4167	6.945	1.077
60	0.220	0.244	4428	3.690	0.572
61	0.156	0.191	4210	2.339	0.363
62	0.052	0.364	4121	1.145	0.178
63	0.052	0.818	7177	1.709	0.265
64	0.156	0.692	8022	4.456	0.691
65	0.156	0.960	6298	5.249	0.814
66	0.156	0.512	6901	3.834	0.595
67	0.091	0.451	7753	2.154	0.334
68	0.091	0.274	4498	1.666	0.258
69	0.556	0.550	12712	15.133	2.347
70	0.556	0.401	5336	12.704	1.971
71	0.556	0.540	9828	14.892	2.310
72	0.556	0.576	8780	15.404	2.389
73	0.556	0.596	7993	16.652	2.583
74	0.306	0.581	7897	8.226	1.276
75	0.306	0.516	7383	7.691	1.193
76	0.091	0.421	2518	2.098	0.325
77	0.091	0.091	2520	0.933	0.145
78	0.052	0.243	2520	0.933	0.145
79	0.197	0.521	8739	4.855	0.753
80	0.197	0.465	7676	4.264	0.661
81	0.197	0.359	6574	3.652	0.567
82	0.291	0.221	8415	4.675	0.725
83	0.291	0.154	7014	3.896	0.604
84	0.291	0.083	5122	2.846	0.441

Table #4 (Cont.)

No of Run.	Height of Opening.	Head.	Q^1 Cu. Ft.	Q^{11} Cu.Ft. Per Sec.	Q cu. ft. per sec per ft. of length.
C 85	0.291	0.042	3660	2.034	0.315
86	0.291	0.022	2695	1.497	0.232
87	0.291	0.165	6056	4.037	0.626
88	0.291	0.756	13271	8.847	1.372
89	0.460	0.229	11761	7.841	1.216
90	0.460	0.182	12601	71001	1.086
91	0.460	0.115	10189	5.661	0.878
92	0.460	0.008	7028	4.685	0.727
93	0.052	0.819	3776	2.098	0.325
94	0.052	0.606	2921	1.623	0.252
95	0.306	0.244	6361	5.301	0.822
96	0.306	0.442	4016	6.693	1.038
97	0.386	0.627	9654	10.724	1.664
98	0.386	0.811	6589	12.201	1.893
99	0.386	0.303	6723	5.934	1.159
100	0.556	0.176	7803	8.750	1.357
101	0.556	0.121	6639	7.377	1.144

Table #5.

No. of Run.	Height of Opening.	Head.	$\sqrt{2gh}$	$\frac{Q}{A}$	Q	$C = \frac{Q}{A\sqrt{2gh}}$
C 9	0.052	0.004	0.508	0.577	0.030	
48		0.055	1.882	1.250	0.065	0.664
41		0.058	1.933	1.327	0.069	0.678
49		0.223	3.790	2.596	0.135	0.685
78		0.243	3.956	2.789	0.145	0.706
62		0.364	4.842	3.423	0.178	0.708
94		0.606	6.247	4.846	0.252	0.775
63		0.818	7.258	5.096	0.265	0.702
93		0.819	7.262	6.250	0.325	0.861
C 4	0.087	0.197	3.562	2.391	0.208	0.672
5		0.333	4.631	3.081	0.268	0.665
6		0.522	0.798	4.000	0.348	0.690
7		0.850	7.399	4.988	0.434	0.674
C 1	0.088	0.011	0.842	0.466	0.041	0.554
2		0.044	1.683	1.091	0.096	0.648
3		0.108	2.637	1.682	0.148	0.638
C 40	0.091	0.076	2.212	1.385	0.126	0.627
77		0.091	2.421	1.594	0.145	0.659
52		0.128	2.871	1.725	0.157	0.601
51		0.179	3.395	2.143	0.195	0.632
68		0.274	4.201	2.835	0.258	0.674
50		0.332	4.624	3.110	0.283	0.673
39		0.402	5.088	3.319	0.302	0.658
76		0.421	5.207	3.572	0.325	0.686
67		0.451	5.389	3.670	0.334	0.682

Table #5 (Cont.)

No. of Run.	Height of Opening.	Head.	$\sqrt{2gh}$	$\frac{Q}{A}$	Q	$C = \frac{C}{A\sqrt{2gh}}$
B 8		0.656	6.500	4.539	0.413	0.699
9		0.716	6.790	4.626	0.421	0.682
C 16	0.102	0.412	5.151	3.579	0.365	0.695
A 14	0.106	0.619	6.314	4.415	0.468	0.699
C 8	0.116	0.824	7.285	4.483	0.520	0.616
B 13	0.131	0.401	5.082	3.656	0.479	0.720
12		0.565	6.032	3.702	0.485	0.614
A 19	0.140	1.078	8.332	6.171	0.864	0.741
C 61	0.156	0.191	3.507	2.327	0.363	0.664
20		0.200	3.589	2.417	0.377	0.673
19		0.386	5.044	3.365	0.525	0.673
66		0.512	5.742	3.680	0.595	0.642
64		0.692	6.676	4.429	0.691	0.664
21		0.762	7.005	4.711	0.735	0.672
65		0.960	7.863	5.218	0.814	0.663
C 29	0.197	0.126	2.841	1.812	0.357	0.638
A 4		0.183	3.433	2.320	0.457	0.676
C 81		0.359	4.808	2.878	0.567	0.599
80		0.465	5.472	3.355	0.661	0.613
28		0.515	5.759	4.137	0.815	0.717
79		0.521	5.792	3.822	0.753	0.661
27		0.587	6.148	4.218	0.831	0.686
A 15		0.697	6.700	4.391	0.865	0.655
C 26		0.700	6.714	4.543	0.895	0.675
A 16		0.941	7.785	5.620	1.107	0.722

Table #5 (Cont.)

No. of Run.	Height of Opening.	Head.	$\sqrt{2gh}$	$\frac{Q}{A}$	Q	$C = \frac{Q}{A\sqrt{2gh}}$
A 17		0.967	7.891	5.310	1.046	0.674
21		1.170	8.680	6.193	1.220	0.713
22		1.261	9.012	6.376	1.256	0.707
C 14	0.212	0.226	3.815	2.656	0.563	0.696
13		0.384	4.973	3.226	0.684	0.649
12		0.385	4.990	3.420	0.725	0.685
10		0.595	6.190	4.198	0.890	0.678
11		0.604	6.237	3.892	0.825	0.624
B 4	0.216	0.292	4.337	3.032	0.655	0.700
3		0.465	5.472	3.907	0.844	0.714
2		0.596	6.195	4.352	0.940	0.703
C 38	0.220	0.125	2.837	1.823	0.401	0.642
37		0.198	3.571	2.323	0.511	0.650
60		0.244	3.874	2.600	0.572	0.672
A 12		0.475	5.531	3.991	0.878	0.721
C 59		0.890	7.571	4.895	1.077	0.646
A 20		1.101	8.420	5.691	1.252	0.678
C 86	0.291	0.022	1.190	0.797	0.232	0.670
85		0.042	1.645	1.082	0.315	0.658
58		0.080	2.270	1.454	0.423	0.640
84		0.083	2.312	1.515	0.441	0.655
47		0.118	2.757	1.794	0.522	0.651
57		0.128	2.871	1.876	0.546	0.653
83		0.154	3.149	2.076	0.604	0.659
87		0.165	3.260	2.151	0.626	0.659
45		0.168	3.289	2.165	0.630	0.658
82		0.221	3.773	2.491	0.725	0.661
A 6		0.229	3.840	2.986	0.869	0.778

No. of Run.	Height of Opening.	Head.	$\sqrt{2gh}$	$\frac{Q}{A}$	Q	$C = \frac{Q}{A\sqrt{2gh}}$
C 56		0.233	3.874	2.460	0.716	0.636
46		0.239	3.923	2.553	0.743	0.650
44		0.300	4.395	2.948	0.858	0.672
55		0.386	4.986	3.134	0.912	0.628
54		0.396	5.050	3.426	0.997	0.679
43		0.479	5.554	3.746	1.090	0.674
A 13		0.481	5.566	3.766	1.096	0.676
C 53		0.551	5.957	3.756	1.093	0.629
42		0.581	6.117	4.086	1.189	0.667
18		0.756	6.978	4.691	1.365	0.672
88		0.756	6.978	4.715	1.372	0.676
17		0.961	7.867	5.182	1.508	0.658
A 18		1.068	8.293	5.248	1.527	0.633
23		1.362	9.365	4.976	1.448	0.532
B 10	0.303	0.363	4.841	3.833	1.025	0.792
11		0.861	7.446	5.086	1.541	0.683
C 36	0.306	0.161	3.220	2.062	0.631	0.640
95		0.244	3.964	2.686	0.822	0.678
96		0.442	5.335	3.392	1.038	0.636
75		0.516	5.765	3.899	1.193	0.675
33		0.566	6.037	4.101	1.255	0.680
74		0.581	6.117	4.170	1.276	0.682
31		0.635	6.395	4.347	1.330	0.679
30		0.762	7.005	4.781	1.463	0.682
32		0.801	7.182	4.847	1.483	0.674

Table # 5 (Cont.)

No. of Run.	Height of Opening.	Head.	$\sqrt{2gh}$	$\frac{Q}{A}$	Q	$C=\frac{Q}{A\sqrt{2gh}}$
A 7	0.314	0.233	3.874	2.752	0.864	0.711
11		0.470	5.502	3.350	1.052	0.609
A 9	0.376	0.285	4.284	2.803	1.054	0.655
10		0.316	4.511	3.053	1.148	0.677
B 7	0.386	0.171	3.319	2.306	0.890	0.695
6		0.214	3.712	2.645	1.021	0.712
C 99		0.303	4.417	3.003	1.159	0.679
B 5		0.392	5.024	3.516	1.357	0.699
C 97		0.627	6.354	4.311	1.664	0.678
98		0.811	7.228	4.904	1.893	0.678
C 92	0.460	0.088	2.381	1.580	0.927	0.6634
91		0.115	2.721	1.909	0.878	0.702
A 3		0.180	3.405	1.872	0.861	0.549
C 90		0.182	3.424	2.361	1.086	0.690
89		0.229	3.840	2.644	1.216	0.688
A 8		0.276	4.216	2.257	1.038	0.535
B 18	0.479	0.232	3.865	2.507	1.201	0.648
14		0.302	4.410	3.027	1.450	0.686
A 2	0.490	0.141	3.013	1.769	0.867	0.585
5		0.206	3.642	2.149	1.053	0.590
C 35	0.556	0.070	2.123	1.516	0.843	0.713
101		0.121	2.791	2.058	1.144	0.737
100		0.176	3.367	2.441	1.357	0.724
34		0.288	4.307	3.092	1.719	0.717
70		0.401	5.082	3.545	1.971	0.697
24		0.503	5.692	4.051	2.252	0.713

Table # 5 (Cont.)

No. of Run.	Height of Opening.	Head.	$\sqrt{2gh}$	$\frac{Q}{A}$	Q	$C = \frac{Q}{A\sqrt{2gh}}$
C 25		0.514	5.753	4.140	2.302	0.718
71		0.540	5.897	4.155	2.310	0.706
69		0.550	5.951	4.221	2.347	0.708
23		0.563	6.021	4.347	2.417	0.721
72		0.576	6.090	4.297	2.389	0.705
73		0.596	6.195	4.646	2.583	0.749
B 17	0.563	0.138	2.981	2.155	1.213	0.722
B 15	0.648	0.153	3.139	2.241	1.452	0.703
B 16	0.820	0.079	2.256	1.460	1.197	0.647

Table #6. Trial Formula log Qc=0.5 log h

No. of Run.	Height of Opening.	Head.	log h.	0.5 log h =log Qc.	log Qm.	Qm.	log Qm- log Qc
C 9	0.052	0.004	-2.3979	-1.1989	-1.5229	0.030	-.3240
48		0.055	-1.2596	-1.6298	-1.1871	0.065	-.5573
41		0.058	-1.2366	-0.6183	-1.1612	0.069	-.5429
49		0.223	-.6517	-.3258	- .8697	0.135	-.5439
78		0.243	- .6144	- .3072	- .8386	0.145	-.5314
62		0.364	- .4389	- .2194	- .7496	0.178	-.5302
94		0.606	- .2175	- .1087	- .5986	0.252	-.4899
63		0.818	- .0872	- .0436	- .5768	0.265	-.5332
93		0.819	- .0867	- .0433	- .4881	0.325	-.4448
C 4	0.087	0.197	- .7055	- .3527	- .6819	0.208	-.3292
5		0.333	- .4776	- .2388	- .5719	0.268	-.3331
6		0.522	- .2823	- .1411	- .4584	0.348	-.3173
7		0.850	- .0706	- .0353	- .3625	0.434	-.3272
C 1	0.088	0.011	-1.9586	- .9793	-1.3872	0.041	-.4079
2		0.044	-1.3565	- .6782	-1.0177	0.096	-.3395
3		0.108	- .9666	- .4833	- .8297	0.148	-.3464
C 40	0.091	0.076	-1.1192	- .5596	- .8996	0.126	-.3400
77		0.091	-1.0410	- .5205	- .8386	0.145	-.3181
52		0.128	- .8928	- .4464	- .8041	0.157	-.3577
51		0.179	- .7471	- .3735	- .7100	0.195	-.3365
68		0.274	- .5622	- .2811	- .5884	0.258	-.3073
50		0.332	- .4789	- .2394	- .5482	0.283	-.3088
39		0.402	- .3958	- .1979	- .5200	0.302	-.3221
76		0.421	-.3757	- .1878	- .4881	0.325	-.3003
67		0.451	- .3458	- .1729	- .4763	0.334	-.3034

Table #6 (Cont.)

No. of Run.	Height of Opening.	Head.	Log h.	0.5 log h =log Qc.	log Qm.	Qm.	log Qm-log Qc
B 8		0.656	-.1831	-.0915	-.3840	0.413	-.2925
9		0.716	-.1451	-.0725	-.3757	0.421	-.3032
C 16	0.102	0.412	-.3851	-.1925	-.4377	0.365	-.2452
A 14	0.106	0.619	-.2083	-.1041	-.3298	0.468	-.2257
C 8	0.116	0.824	-.0841	-.0420	-.2840	0.520	-.2420
B 13	0.131	0.401	-.3969	-.1984	-.3197	0.479	-.1213
12		0.565	-.2480	-.1440	-.3143	0.485	-.1703
A 19	0.140	1.078	.0326	.0163	-.0635	0.864	-.0798
C 61	0.156	0.191	-.7190	-.3595	-.4401	0.363	-.0806
20		0.200	-.6990	-.3495	-.4237	0.377	-.0742
19		0.386	-.4134	-.2067	-.2798	0.525	-.0731
66		0.512	-.2907	-.1453	-.2255	0.595	-.0602
64		0.692	-.1599	-.0799	-.1605	0.691	-.0806
21		0.762	-.1180	-.0590	-.1337	0.735	-.0747
65		0.960	-.0177	-.0088	-.0894	0.814	-.0806
C 29	0.197	0.126	-.8996	-.4498	-.4473	0.357	.0025
A 4		0.183	-.7375	-.3687	-.3401	0.457	.0286
C 81		0.359	-.4449	-.2224	-.2464	0.567	-.0240
80		0.465	-.3325	-.1662	-.1798	0.661	-.0136
28		0.515	-.2882	-.1441	-.0888	0.815	.0553
79		0.521	-.2832	-.1416	-.1232	0.753	.0184
27		0.587	-.2314	-.1257	-.0804	0.831	.0453
A 15		0.697	-.1568	-.0784	-.0630	0.865	.0154
C 26		0.700	-.1549	-.0774	-.0482	0.895	.0292
A 16		0.941	-.0264	-.0132	.0441	1.107	.0573
17		0.967	-.0146	-.0073	.0195	1.046	.0268
21		1.170	.0682	.0341	.0864	1.220	.0523
22		1.261	.1007	.0503	.0990	1.256	.0487

Table #6 (Cont.)

No. of Run.	Height of Opening.	Head.	Log h.	0.5 log h =log Qc.	log Qm.	Qm.	log Qm- log Qc.
C 14	0.212	0.226	- .6459	- .3229	- .2495	0.563	.0734
13		0.384	- .4517	- .2078	- .1649	0.684	.0429
12		0.385	- .4145	- .2072	- .1397	0.725	.0675
10		0.595	- .2255	- .1127	- .0506	0.890	.0621
11		0.604	- .2190	- .1095	- .0835	0.825	.0260
B 4	0.216	0.292	- .5346	- .2673	- .1838	0.655	.0835
3		0.465	- .3325	-.1662	- .0737	0.844	.0925
2		0.596	- .2248	- .1124	- .0269	0.940	.0855
C 38	0.220	0.125	- .9031	- .4515	- .3969	0.401	.0546
37		0.198	- .7033	- .3516	- .2916	0.511	.0600
60		0.244	- .6126	- .3063	- .2426	0.572	.0537
A 12		0.475	- .3233	- .1616	- .0565	0.878	.1051
C 59		0.890	- .0506	- .0253	.0322	1.077	.0575
A 20		1.101	.0418	.0209	.0976	1.252	.0767
C 86	0.291	0.022	-1.6576	- .8288	- .6345	0.232	.1943
85		0.042	-1.3768	- .6884	- .5017	0.315	.1767
58		0.080	-1.0969	- .5484	- .3737	0.423	.1747
84		0.083	-1.0809	- .5404	- .3556	0.441	.1848
47		0.118	- .9281	- .4640	- .2823	0.522	.1817
57		0.128	-.8928	- .4464	-.2628	0.546	.1836
83		0.154	- .8125	- .4062	- .2190	0.604	.1872
87		0.165	- .7825	- .3912	- .2034	0.626	.1878
45		0.168	- .7747	- .3873	- .2007	0.630	.1866
82		0.221	- .6556	- .3278	- .1397	0.725	.1881
A 6		0.229	- .6402	- .3201	- .0610	0.869	.2591
C 56		0.233	- .6326	- .3163	- .1451	0.716	.1712
46		0.239	- .6216	- .3108	- .1290	0.743	.1818
44		0.300	- .5229	- .2614	- .0665	0.858	.1949

No. of Run.	Height of Opening.	Head.	Log h.	0.5 log h =log Qc.	log Qm.	Qm.	log Qm-log Qc.
C 55		0.386	-.4134	-.2069	-.0400	0.912	.1667
54		0.396	-.4023	-.2011	-.0013	0.997	.1998
43		0.479	-.3197	-.1548	.0374	1.090	.1922
A 13		0.481	-.3179	-.1589	.0398	1.096	.1987
C 53		0.551	-.2588	-.1294	.0386	1.093	.1680
42		0.581	-.2358	-.1179	.0752	1.189	.1931
18		0.756	-.1215	-.0607	.1351	1.365	.1958
88		0.756	-.1215	-.0607	.1374	1.372	.1981
17		0.961	-.0173	-.0086	.1784	1.508	.1870
A 18		1.068	.0286	.0143	.1838	1.527	.1695
23		1.362	.1342	.0671	.1608	1.448	.0937
B 10	0.303	0.363	-.4401	-.2200	.0107	1.025	.2307
11		0.861	-.0650	-.0325	.1878	1.541	.2203
C 36	0.306	0.161	-.7932	-.3966	-.2000	0.631	.1966
95		0.244	-.6126	-.3063	-.0851	0.822	.2212
96		0.442	-.3546	-.1773	.0162	1.038	.1935
75		0.516	-.2874	-.1437	.0766	1.193	.2203
33		0.566	-.2472	-.1236	.0986	1.255	.2222
74		0.581	-.2358	-.1179	.1059	1.276	.2238
31		0.635	-.1972	-.0986	.1239	1.330	.2225
30		0.762	-.1180	-.0590	.1652	1.463	.2242
32		0.801	-.0864	-.0432	.1711	1.483	.2143
A 7	0.314	0.233	-.6326	-.3163	-.0635	0.864	.2528
11		0.470	-.3279	-.1639	.0220	1.052	.1859
A 9	0.376	0.285	-.5452	-.2726	.0228	1.054	.2954
10		0.316	-.5003	-.2501	.0599	1.148	.3100
B 7	0.386	0.171	-.7670	-.3835	-.0506	0.890	.3329
6		0.214	-.6696	-.3348	.0090	1.021	.3438

No. of Run.	Height of Opening.	Head.	Log h.	0.5 log h =log Qc.	log Qm.	Qm.	log Qm- log Qc.
C 99		0.303	-.5186	-.2593	.0641	1.159	.3234
B 5		0.392	-.4067	-.2033	.1326	1.357	.3359
C 97		0.627	-.2027	-.1013	.2212	1.664	.3225
98		0.811	-.0910	-.0455	.2772	1.893	.3227
C 92	0.460	0.088	-1.0555	-.5277	-.1385	0.727	.3892
91		0.115	-.9393	-.4696	-.0565	0.878	.4131
A 3		0.180	-.7447	-.3723	-.0650	0.861	.3073
C 90		0.182	-.7399	-.3699	.0358	1.086	.4057
89		0.229	-.6402	-.3201	.0849	1.216	.4050
A 8		0.276	-.5591	-.2795	.0162	1.038	.2957
B 18	0.479	0.232	-.6345	-.3172	.0795	1.201	.3967
14		0.302	-.5200	-.2600	.1614	1.450	.4214
A 2	0.490	0.141	-.8508	-.4254	-.0620	0.867	.3623
5		0.206	-.6861	-.3430	.0223	1.053	.3654
C 35	0.556	0.070	-1.1549	-.5774	-.0742	0.843	.5032
101		0.121	-.9172	-.4586	.0584	1.144	.5170
100		0.176	-.7545	-.3772	.1326	1.357	.5098
34		0.288	-.5406	-.2703	.2353	1.719	.5056
70		0.401	-.3969	-.1984	.2947	1.971	.4931
24		0.503	-.2984	-.1492	.3526	2.252	.5018
25		0.514	-.2890	-.1445	.3621	2.302	.5066
71		0.540	-.2674	-.1337	.3636	2.310	.4973
69		0.550	-.2596	-.1298	.3705	2.347	.5003
23		0.563	-.2495	-.1247	.3833	2.417	.5080
72		0.576	-.2396	-.1198	.3782	2.389	.4980
73		0.596	-.2248	-.1124	.4121	2.583	.5245
B 17	0.563	0.138	-.8601	-.4300	.0839	1.213	.5139
B 15	0.648	0.153	-.8153	-.4076	.1620	1.452	.5696
B 16	0.820	0.079	-11024	-.5512	.0781	1.197	.6293

Table #7.

Values read from curves on Sheet #2.

Values used to plot curves on sheet #3.

Height of Opening.	log m.	Height of Opening	log m.
0.052	-0.53	0.305	0.22
0.089	-0.32	0.386	0.33
0.156	-0.08	0.460	0.405
0.197	0.026	0.556	0.505
0.216	0.065	0.648	0.57
0.291	0.19	0.820	0.727

Table #8.

Values read from curves on Sheet #4.

Height of Opening.	Limits of Curves. Logs of Heads Upper.	Lower.	Intercepts on Lines. Log h=0	Log h = -1.0
0.052	0.00	-1.30	-0.526	-1.040
0.098	0.00	-1.40	-0.300	-0.838
0.156	0.00	-0.75	-0.080	-0.570
0.197	0.10	-0.90	0.036	-0.496
0.216	0.10	-0.90	0.076	-0.446
0.291	0.15	-1.70	0.196	-0.316
0.305	-0.05	-0.80	0.222	-0.278
0.386	-0.05	-.080	0.326	-0.174
0.460	-0.55	-1.05	0.405	-0.095
0.556	-0.20	-1.20	0.496	0.016

Above values were used to plot the curves on Sheet #5.

Table #9.

Values determined from curves on Sheet #5.

Height of Opening.	Intercepts on Lines. Log h = 0	Log h = -1.0	Height of Opening.	Intercepts on Lines Log h=0	Log h=-1.0
0.05	-0.54	-1.06	0.22	0.08	-0.436
0.06	-0.46	-0.99	0.24	0.113	-0.399
0.07	-0.40	-0.935	0.26	0.146	-0.364
0.08	-0.345	-0.885	0.28	0.18	-0.33
0.09	-0.30	-0.838	0.30	0.21	-0.30
0.10	-0.26	-0.79	0.32	0.24	-0.269
0.11	-0.22	-0.75	0.34	0.266	-0.24
0.12	-0,185	-0.71	0.36	0.293	-0.213
0.13	-0.15	-0.67	0.38	0.318	-0.188
0.14	-0.12	-0.635	0.40	0.34	-0.165
0.15	-0.09	-.060	0.42	0.364	-0.14
0.16	-0.06	-0.572	0.44	0.387	-0.116
0.17	-0.03	-0.545	0.46	0.407	-0.095
0.18	-0.005	-0.523	0.48	0.428	-0.07
0.19	0.02	-0.50	0.50	0.45	-0.05
0.20	0.04	-0.475	0.55	0.49	0.00

The above values were used in plotting the height of opening lines on Sheet # 6.